Modeling and pattern informatics of remotely sensed crustal deformation data, seismicity, and geologic observations for improved earthquake forecasting

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Early Warning

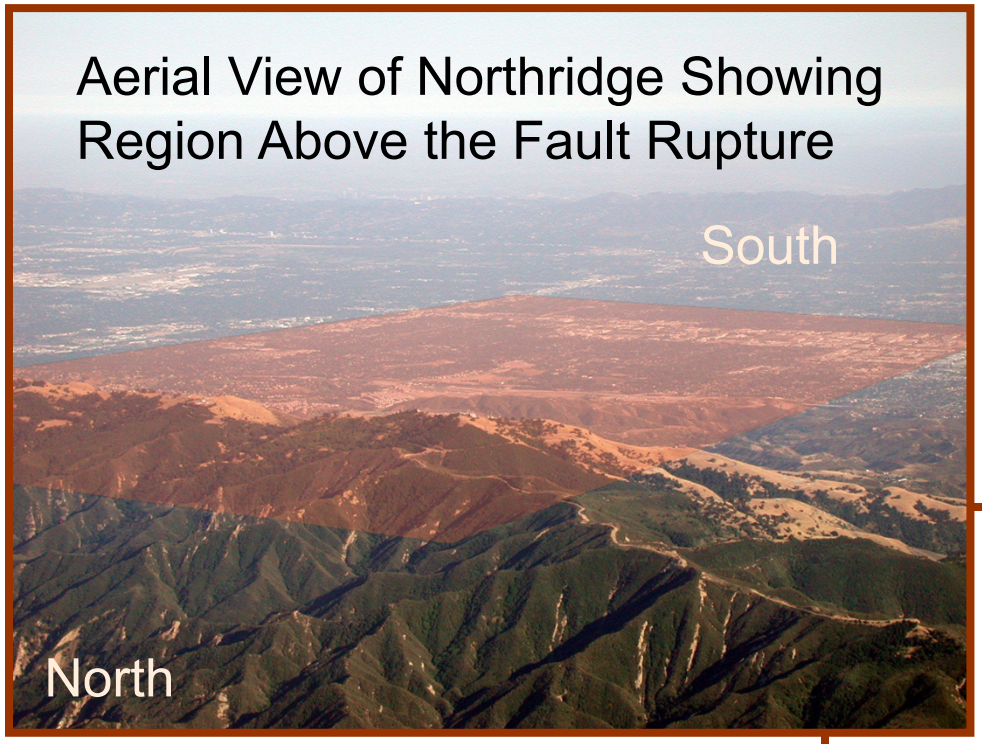
- Crustal deformation does well for location and style of faulting
- What about
  - Timescales
  - Non-linear mechanics
  - Transients

Bootstrapping Approach

- NASA is a research agency
- Use science to inform the forecasts
  - .e.g Northridge earthquake
- Use forecasts to inform the science
  - e.g. UAVSAR measurements of southern California
- Science is exploratory
  - We should explore, test, validate, and *integrate* all of the approaches
- Need to move the research to validated operational systems for decision making

This group is a potential venue for testing, validating, and integrating as appropriate into the science *and* decision making

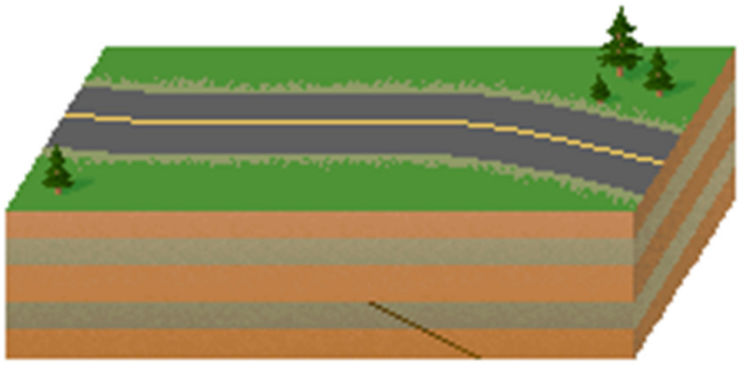
GPS Results Indicated Active Faults Near Northridge



"…would yield an earthquake of moment magnitude $M_w \approx 6.4$… and a $M_w \approx 6$ earthquake is still large and potentially damaging."

Donnellan et al., Nature, November 25, 1993.

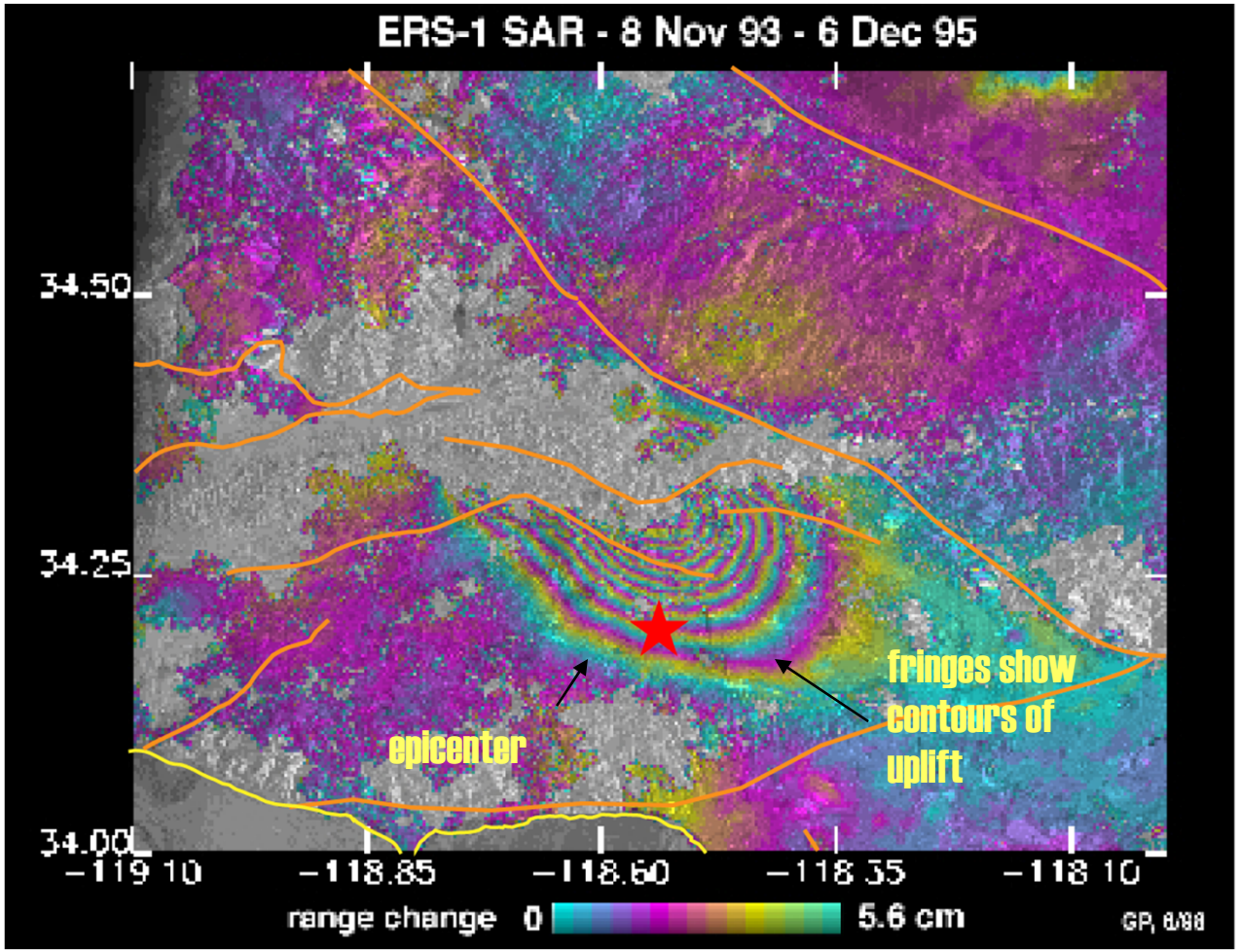
Strain accumulation indicated active faults associated with the M 6.7 Northridge earthquake



Northridge occurred on a blind thrust fault that was best matched by the pre-earthquake models

The Northridge Earthquake was Observed with InSAR

40 cm uplift as a result of the Northridge earthquake

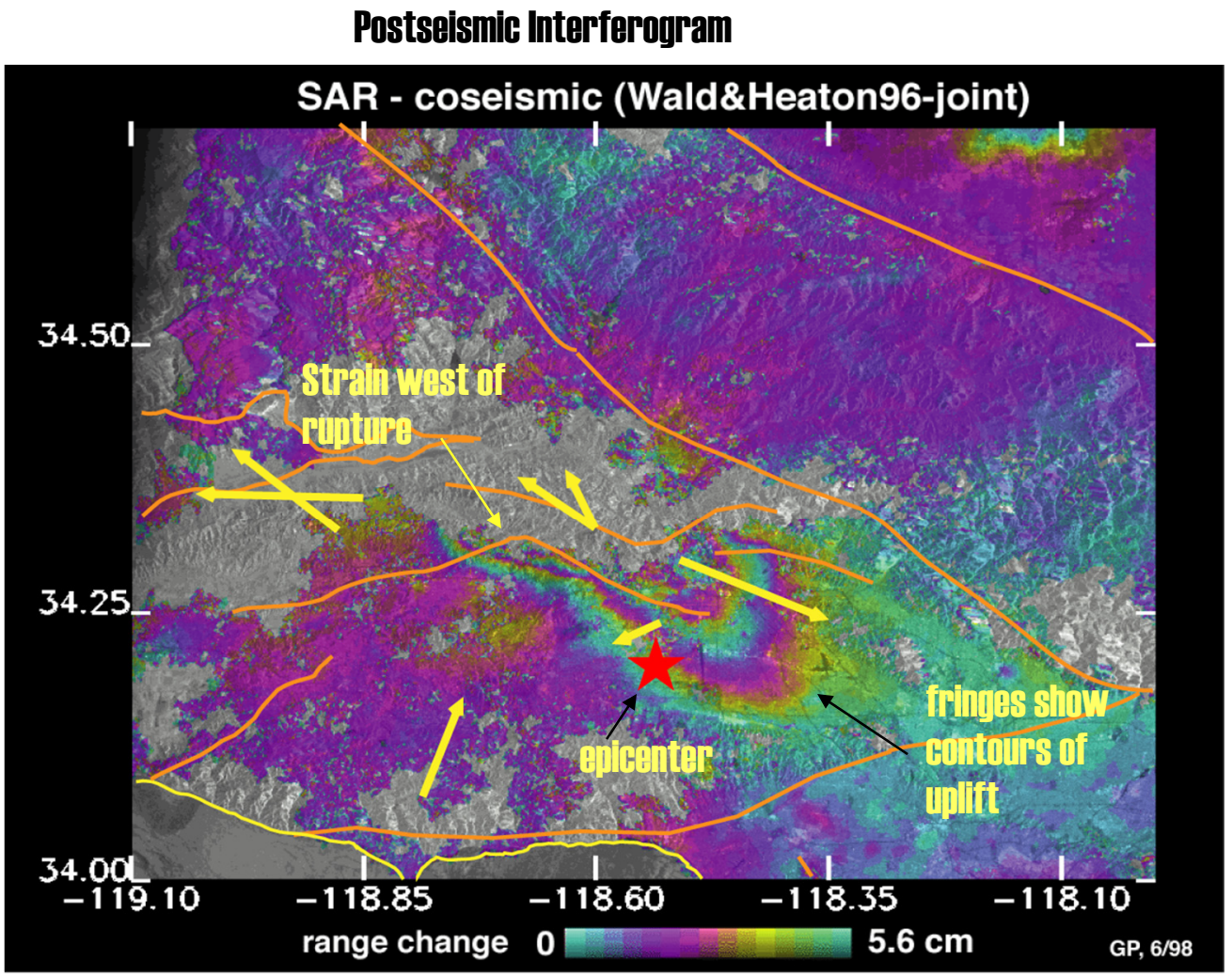


1993–1995 Interferogram

Northridge Postseismic Motion was Observed with InSAR and GPS

12 cm postseismic uplift over two years

90% of the motion was aseismic



DESDynI Decadal Surey Mission just passed Mission Confirmation Review (MCR)
Target launch of 2017; 13 day repeat interval

Forecasts

- Bootstrapping approach
  - Using forecasts to inform the science
- November 2007 Abstract in proposal to NASA:

  We propose to observe seismically and tectonically active regions in northern and southern California using UAVSAR to support EarthScope activities. We will test the earthquake forecasting methodology developed by Rundle through NASA's QuakeSim project by observing regions indicated as having high probability for earthquakes in the near future (5–10 years). The UAVSAR flights will serve as a baseline for pre-earthquake activity. Should an earthquake occur during the course of this project, we will also be able to observe postseismic motions associated with the earthquakes.

Forecast Map

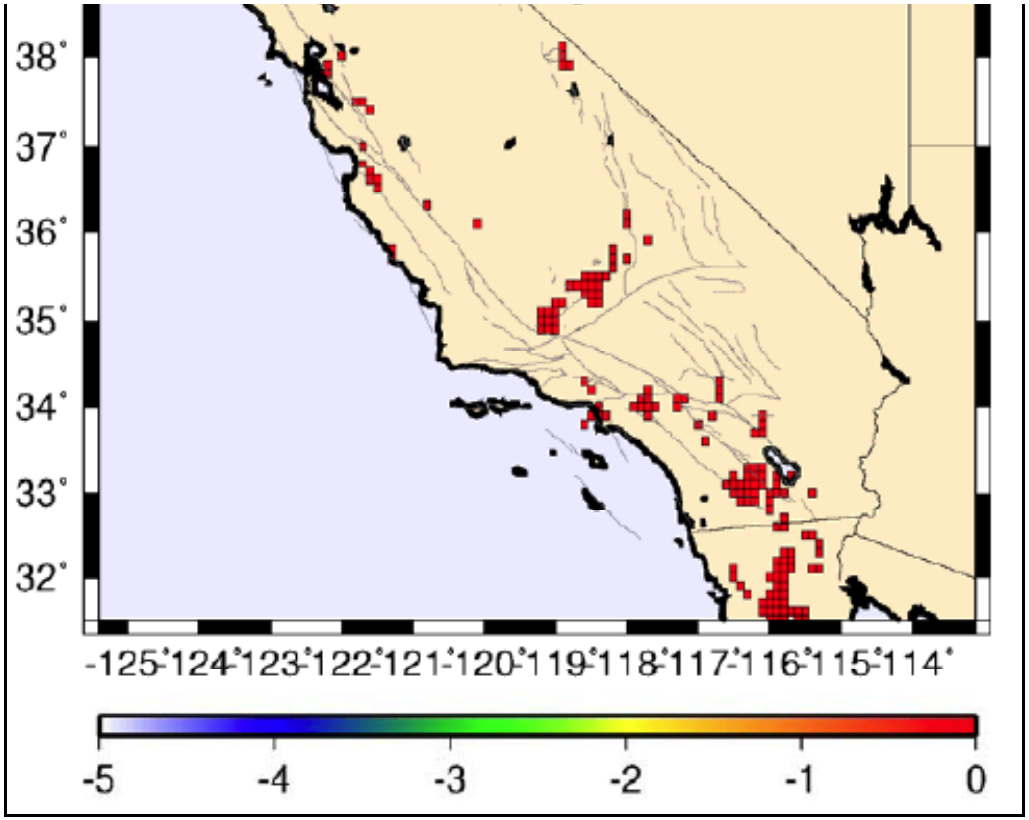
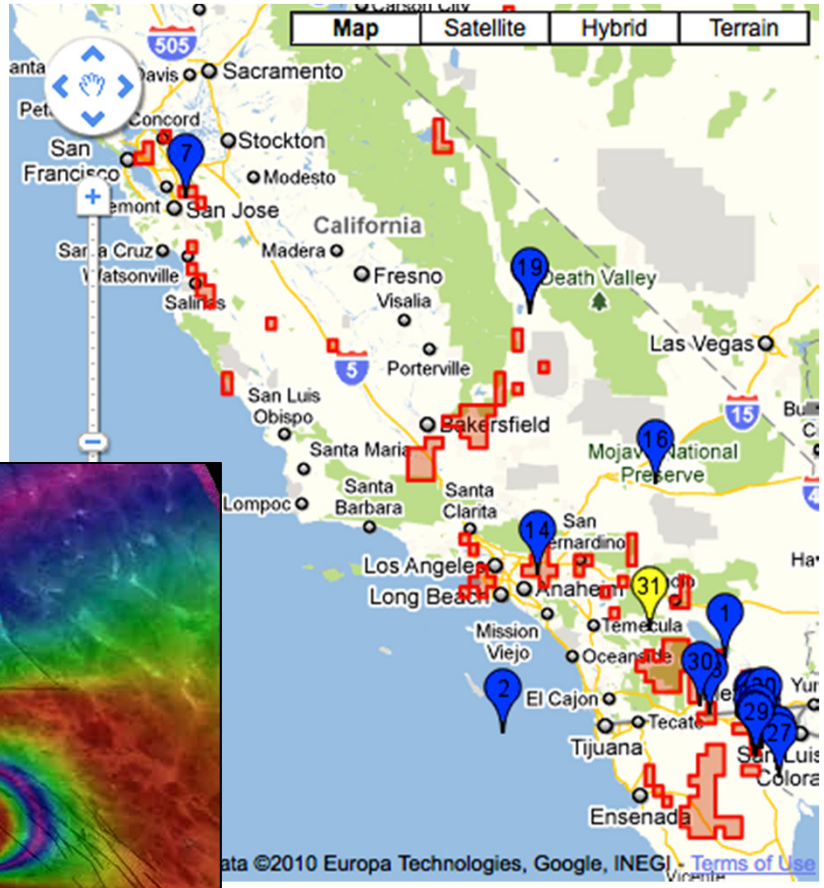
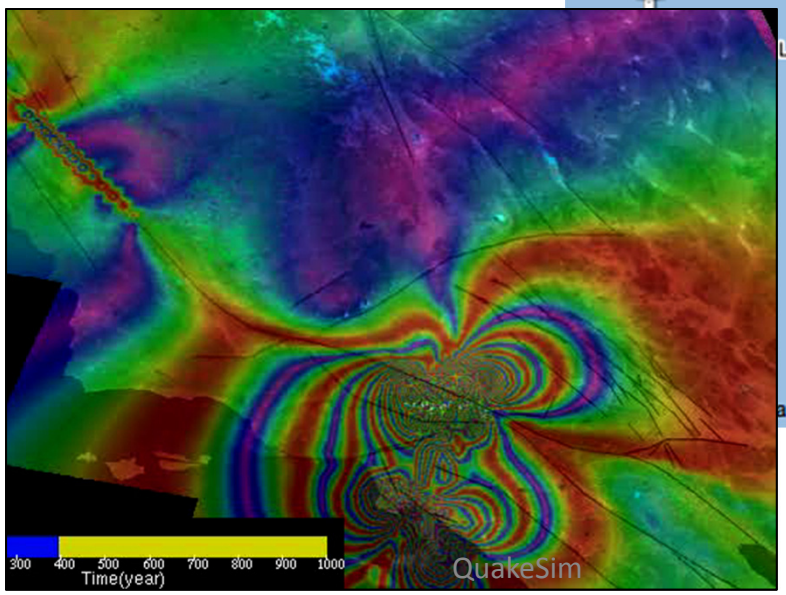


Figure 1. Pattern informatics (PI) map for the California and surrounding region cropped to better show the regions of interest in this proposal. Data from 1950–2005 were used. Map is a forecast of where earthquakes are expected to occur during a futre time window of 5–10 years. Color figure from Holliday et al., 2007.

QuakeSim: Earthquake Modeling and Forecasting

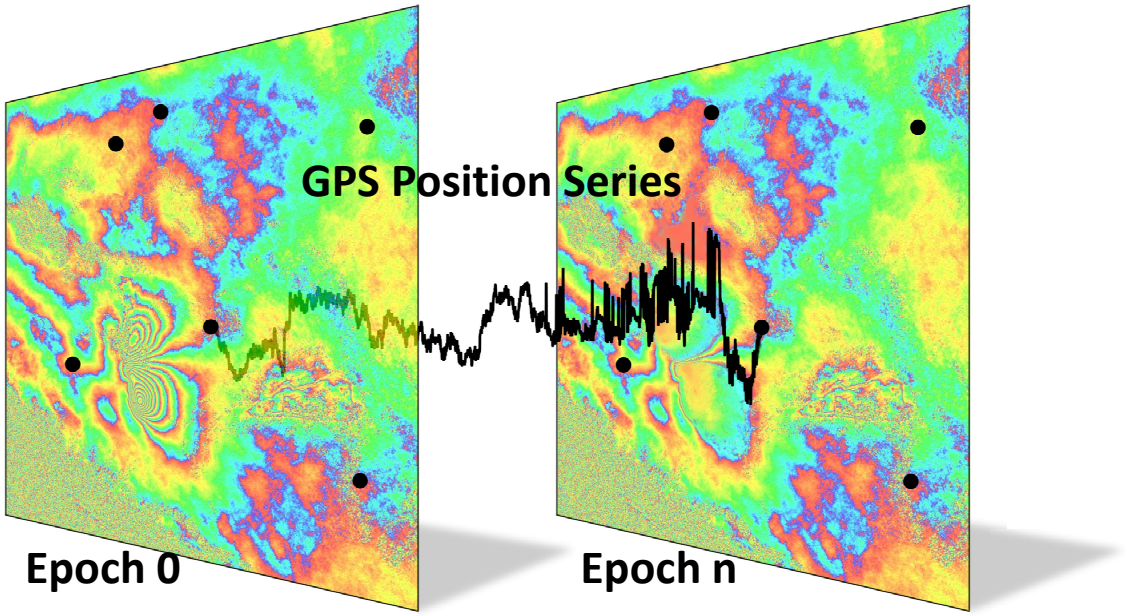
- Simulating and forecasting earthquakes
  - Fault systems
  - Focus on the entire earthquake cycle
- Integrates data and models
  - Radar
  - GPS
  - Seismicity
  - Fault data





Constraining InSAR Imagery with GPS

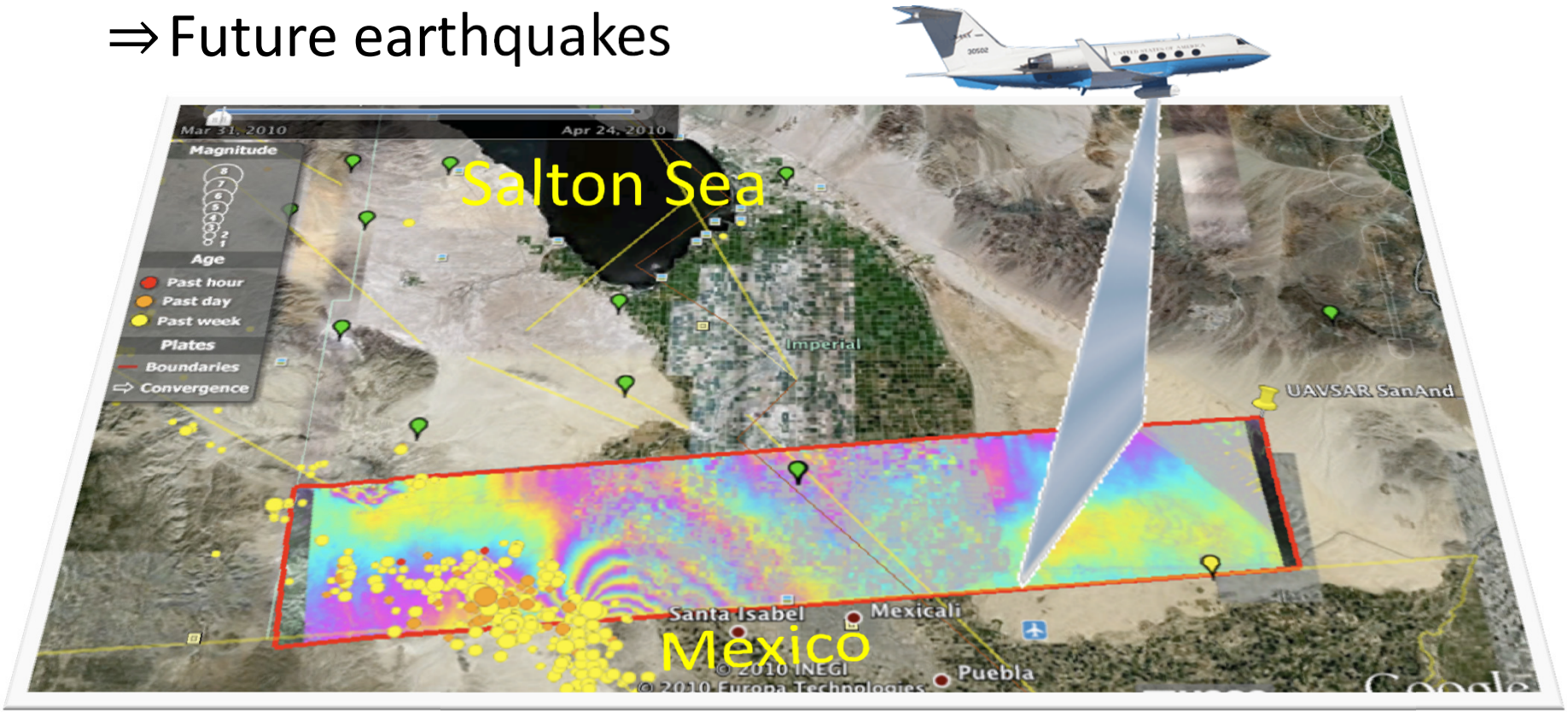
- InSAR images have good spatial but poor temporal coverage (even at an 8-day repeat interval)
- GPS networks have only point-wise spatial coverage, but good temporal coverage
- GPS bridges the temporal gaps between InSAR images
- InSAR bridges the spatial gaps between GPS stations



First UAVSAR Measurement of an Earthquake

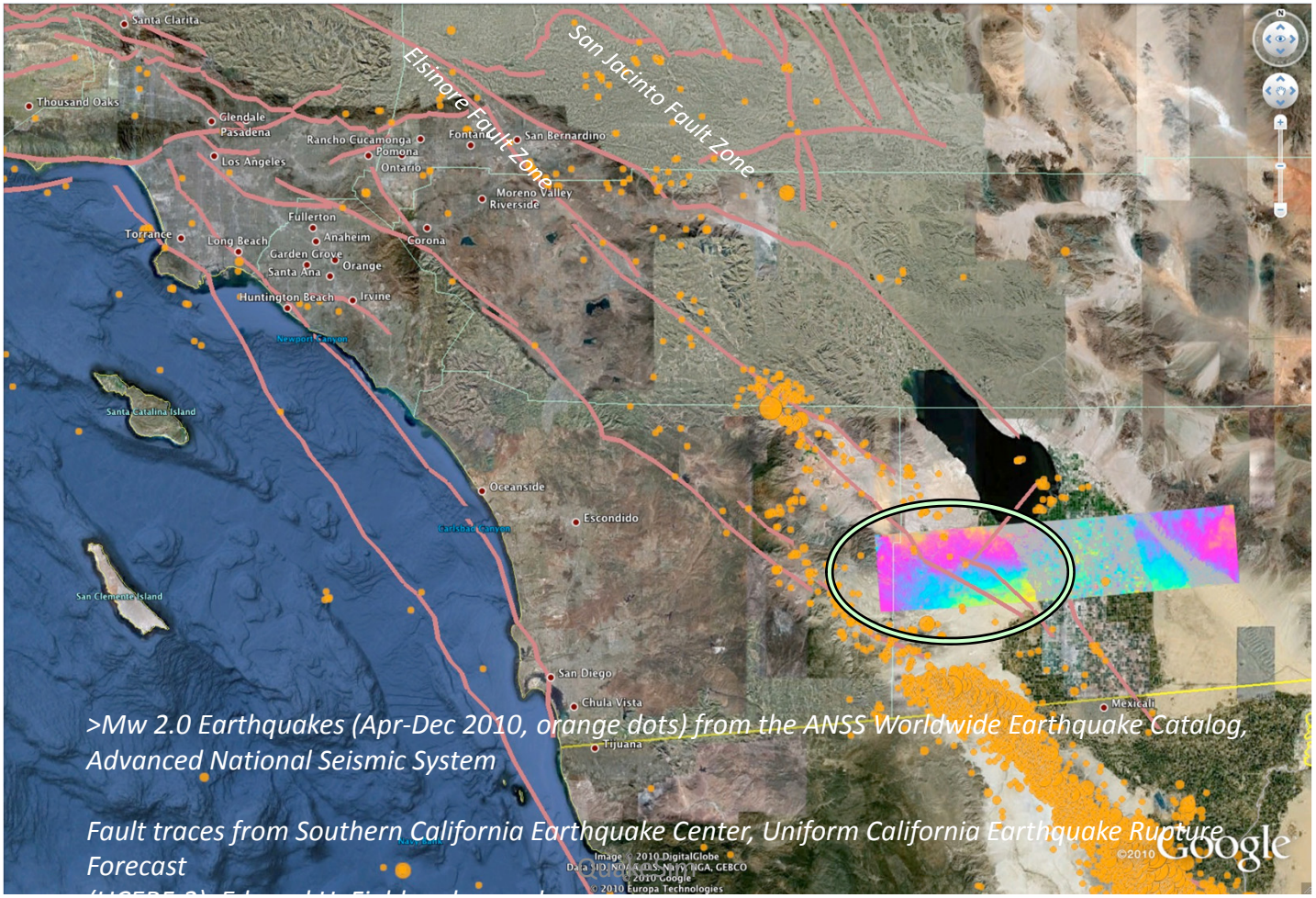
- **Response:** Displacement and disturbance maps
- **Forecasting:** Strain migration

  ⇒ Future earthquakes



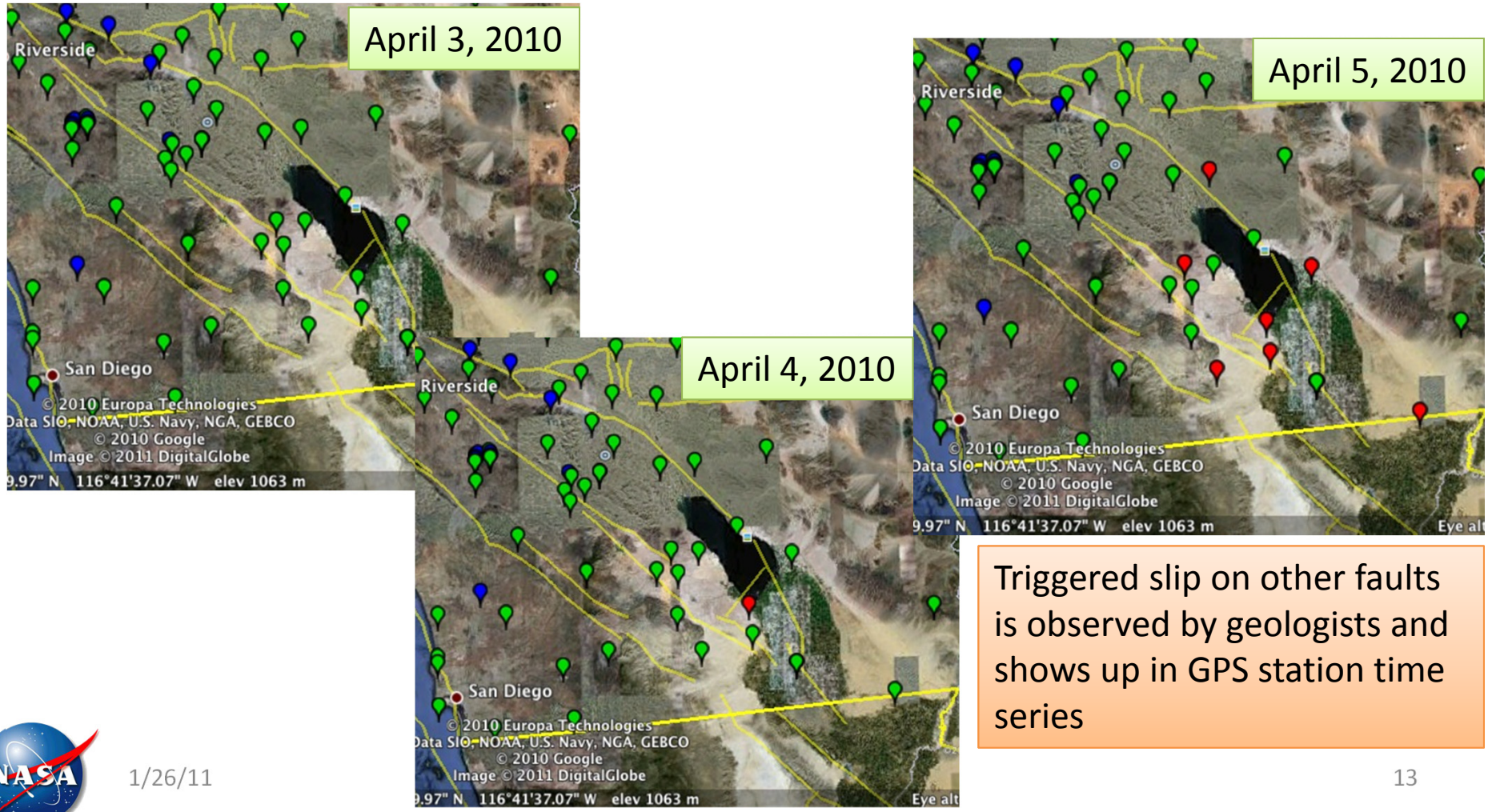
Quake Triggers Responses on Key Faults

- Elsinore fault extends into Los Angeles (nearly all is historically quiet: building stress)
- San Jacinto fault reaches to San Bernardino (historic quakes are >100 yr or far south)
- Full-length ruptures must be considered: damaging earthquakes



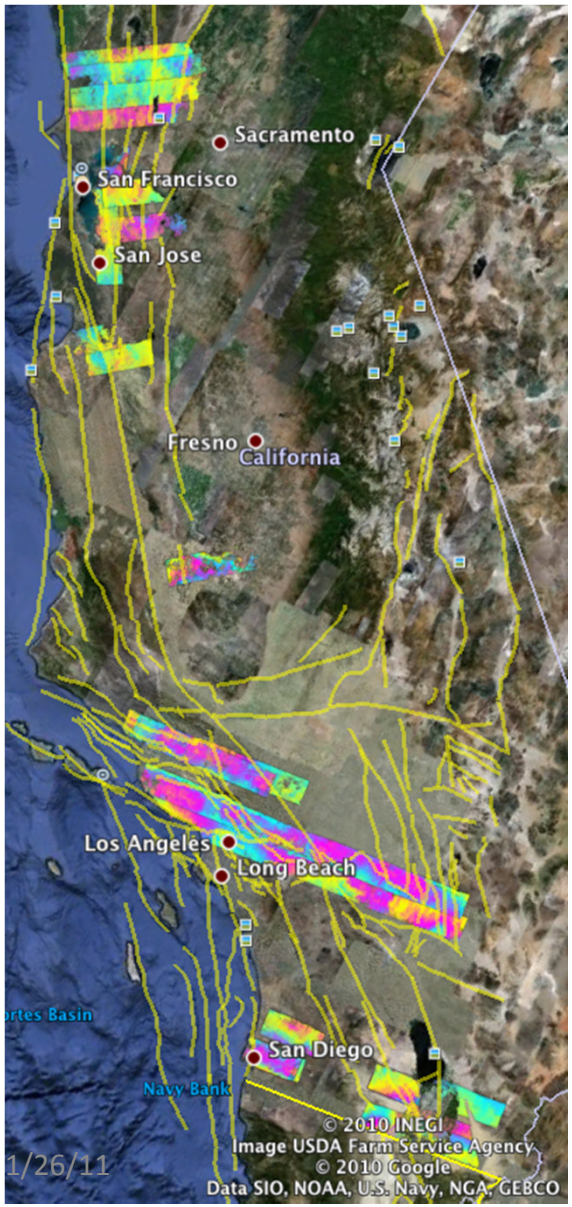
GPS Time Series State Changes

Regularized Deterministic Annealing Hidden Markov Model (RDHAMM) developed by Robert Granat, JPL



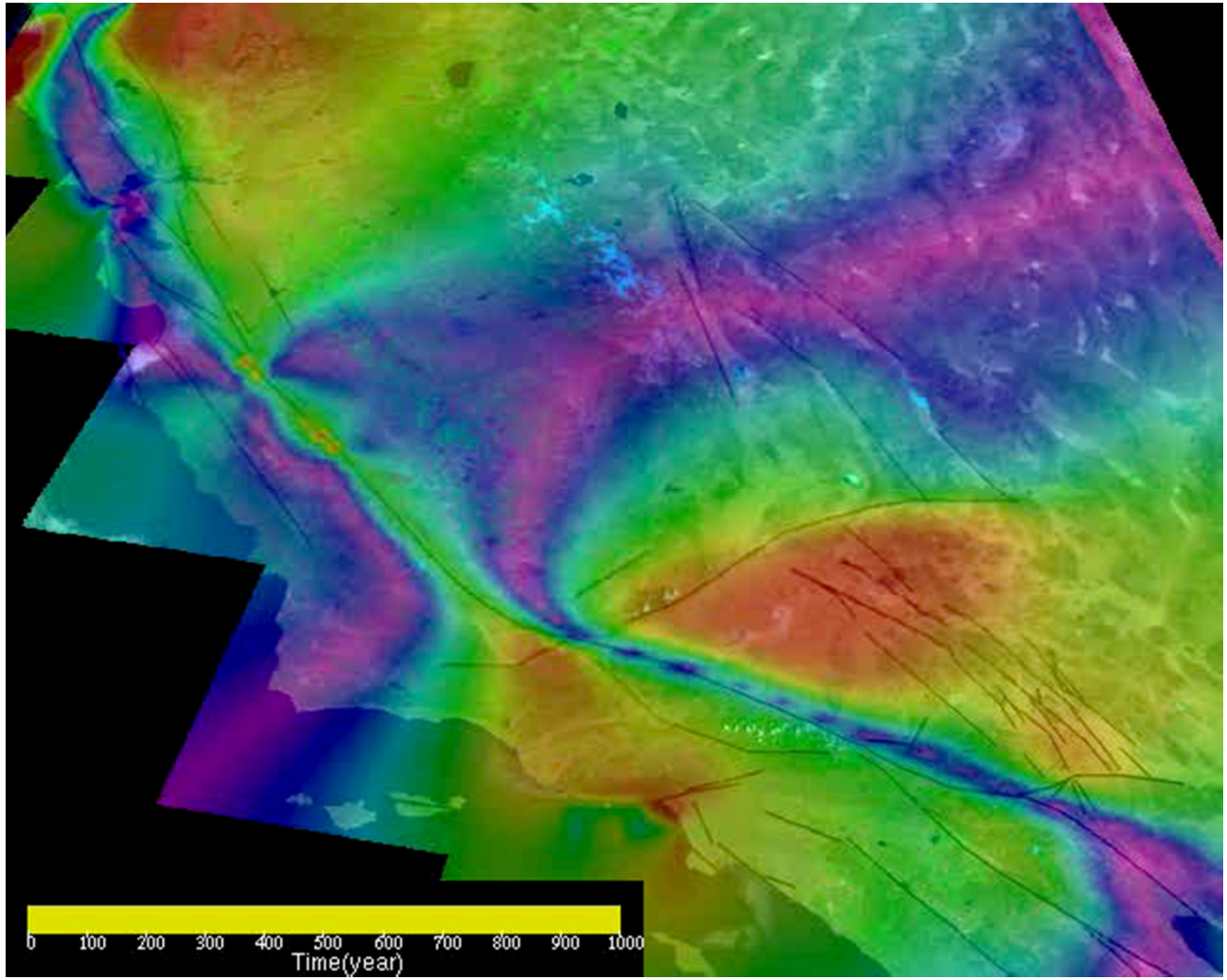
Triggered slip on other faults is observed by geologists and shows up in GPS station time series

UAVSAR



- Implications of El-Mayor/Cucapah earthquake on Los Angeles?
- UAVSAR will provide systematic long-term measurements

Need to Understand Fault Interactions



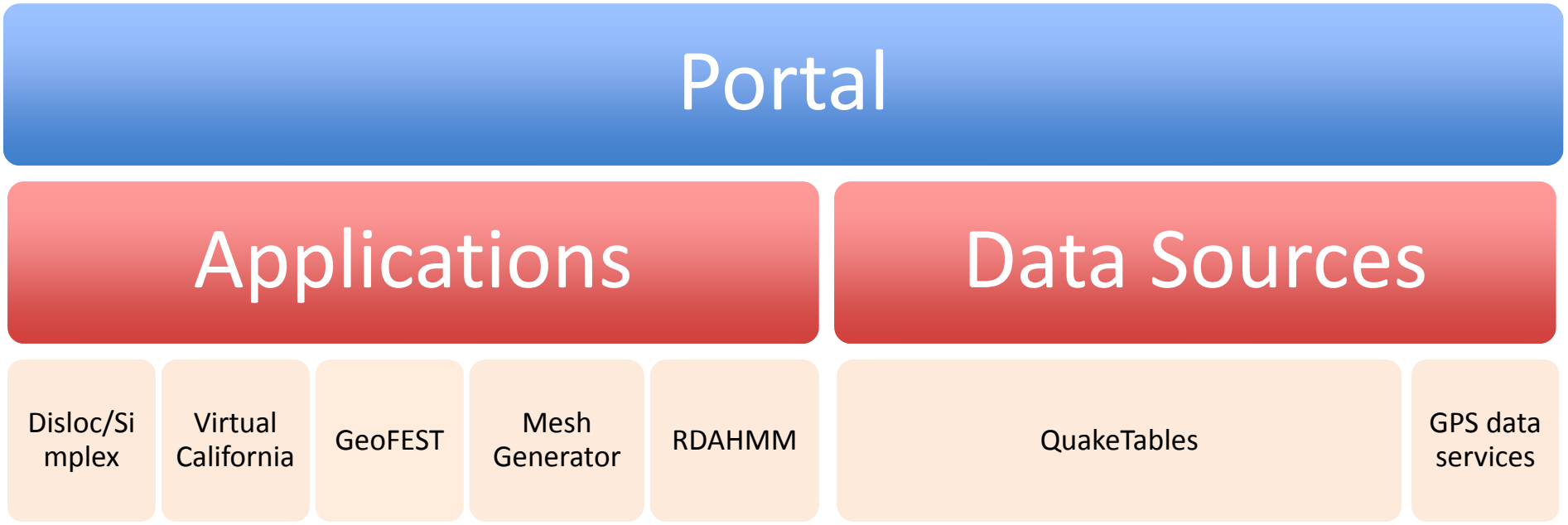
1000 years of simulated earthquakes

- Study correlations between events
- San Andreas events typically follow, but do not precede Eastern California Shear Zone Events
- Southern California long faults tend to follow Baja Earthquake type events

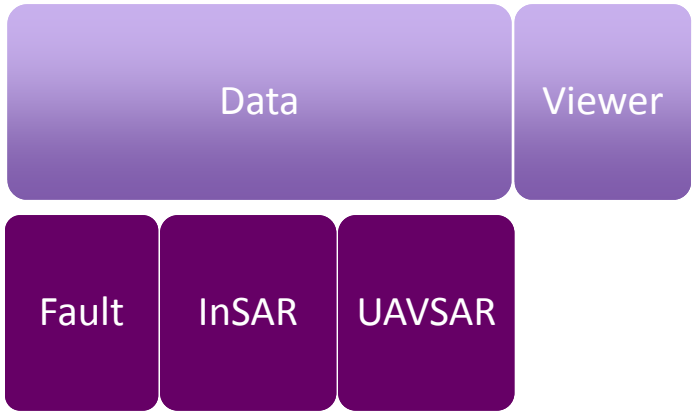
Need Computational Infrastructure

- Study earthquakes on the system level
- Need good information on the science end too
  - Good infrastructure allows for efficient assessment and analysis of data
- Standards
  - Data formats
  - Visualization
- A well thought out system can inform the science and the decisions while iteratively improving on both

Infrastructure



- Standard architecture
- Standard formats
- But otherwise distributed in nature



Summary

- Use data to inform the science
  - Need good data
  - Need to efficiently evaluate the data
- Use the science to inform new data collections
- Integrate all of the methods
  - Testing
  - Validation
  - Standards
- Do this in partnership with decision makers for more rapid ingestion into operational systems